[1]UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Juneau, Alaska

JUN 29 1964

APR 28 1964

District Engineer
U.S. Army Engineer District, Alaska
Corps of Engineers
P.O. Box 7002
Anchorage, Alaska

Dear Sir:

This letter constitutes the report of the U.S. Fish and Wildlife Service regarding effects that the proposed Rampart Canyon Dam and Reservoir project, Yukon River, Alaska would have on fish and wildlife resources. Conclusions and recommendations presented in this letter are based on the results of studies which are discussed in detail in the attached substantiating report. It is furnished for inclusion in the Survey Report of the Corps of Engineers and has been prepared under the authority and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.).

The report is based on engineering data provided by the Corps of Engineers, Alaska District, through December 1963. Our analysis is based on a project with an economic life of 100 years. This report has been furnished to the Alaska Department of Fish and Game for its review. A copy of that Department's comments will be provided to you when they are received.

Rampart Canyon Dam would be located near the geographic center of Alaska at river mile 756 on the Yukon River. It would be built primarily for the purpose of generating electrical power. Flood control, navigation and recreation would be additional purposes. The concrete, gravity-type dam would be 530 feet high and would have a top length of 4,700 feet. It would create a reservoir with a surface area of about 10,500 square miles. The normal reservoir drawdown in winter would be 4 to 5 feet; however, a succession of dry years would result in a maximum drawdown of about 15 feet. The impoundment would be 280 miles long and would have a maximum width of 80 miles. It would inundate 400 river miles of the mainstem Yukon River and an additional 12,600 miles of tributaries. Capacity of the reservoir would be 1.3 billion acre-feet. A period of about 20 years would be required to fill the reservoir. The reservoir would not be cleared prior to filling except in limited areas as required for recreation and navigation.

---

[1] Reprinted by the Alaska Conservation Society from report of USFWS on Rampart Canyon Dam and Reservoir Project, Yukon River, Alaska. Copies of the entire report may be obtained on request from USFWS, Regional Director, Bureau of Commercial Fisheries, Juneau, Alaska.

POLAR
PAM
4588
POLARPAM

BOREAL INSTITUTE
LIBRARY
18425

FISH RESOURCES AND PROJECT EFFECTS

The Yukon River basin supports populations of anadromous and resident fish of importance to the people of the State of Alaska and the Yukon Territory, Canada. The anadromous fish include all five species of Pacific salmon: chinook (king), chum (dog), coho (silver), pink (humpback), and sockeye (red). Smelts and lampreys also occur in the Yukon drainage. Of the salmon only coho, chum, and chinook salmon migrate upstream beyond the Rampart Canyon damsite. Resident fish that would be affected by the project include northern pike, Arctic grayling, whitefishes, ciscoes, longnose suckers, inconnu (sheefish), burbot, lake chubs, trout-perch, and sculpins. Certain of these species move past the damsite in pronounced seasonal migrations.

Anadromous Fish

Based on 2 years of study, the annual number of chinook salmon passing the damsite is estimated to be 20,000 and that of chum salmon 200,000. Coho salmon pass the damsite in peak numbers in the fall during the period of ice formation on the river. Because of this, estimation of the magnitude of the run is difficult. Based on catch ratios of coho salmon to chinook and chum salmon and on other criteria, it is estimated that 50,000 coho salmon pass the damsite on their annual spawning migrations. Estimates above, totaling 270,000 salmon, are believed to be minimal.

Nowhere in the world do spawning runs of chinook, chum, and coho salmon ascend rivers for such great distances as they do in the Yukon River system. Some chinook salmon travel almost 2,000 miles from the Bering Sea and chum and coho salmon have been known to travel in excess of 1,700 miles. On such spawning runs these fish traverse the State of Alaska from west to east and move into tributary streams located in Yukon Territory, Canada. Considerable sums of money have been spent in Canada to assure passage of these spawning fish around existing dams constructed near Whitehorse, Yukon Territory. The Yukon River salmon, because of the high oil content of their flesh, are well adapted to such long migrations. This characteristic also makes them highly prized for food.

Salmon produced in the Yukon River drainage upstream from the Rampart Canyon damsite contribute significantly to commercial fisheries at the mouth of the Yukon, but are most important in providing a subsistence fishery for people residing along the river and its tributaries, both in the State of Alaska and in Yukon Territory, Canada. The average annual combined catch of chinook, chum, and coho salmon from the Yukon River in both commercial and subsistence fisheries approximates 800,000 fish. This harvest would not be expected to change significantly under conditions without the project during the 100-year period of analysis.

With the project in operation, the valuable salmon resources would be severely reduced. The dam would block spawning runs of salmon. As a result the subsistence and commercial fisheries for these fish in areas upstream from the dam would be totally destroyed. The contribution which the fish spawning upstream from the dam would have made to the subsistence and commercial fisheries downstream from the dam would be eliminated. This would result in a loss of catch in the subsistence fishery and the commercial fishery of the Yukon River system of an estimated 200,000 to 400,000 salmon annually.

esident Fish

he magnitude of the subsistence fishery for resident fish is difficult to assess. ative people of the area harvest these fish for use as food for themselves and their ogs. This harvest is mostly incidental to the salmon fishery, although some fishing ffort is expended specifically for whitefish and northern pike. During the period f analysis without the project, the estimated annual catch of resident fish taken by he subsistence fishery within the impoundment area would average 88,000 pounds.

commercial fishery for resident fish does not exist nor would one be expected to evelop without the project during the period of analysis.

xcellent sport fishing opportunities for resident fish are available throughout much f the impoundment area. Fishing pressure is low because of limited access and the mall human population. Most of the sport fishing is accomplished by local people. nder conditions that would obtain without project construction, access would be xpected to improve, thus enabling more people to visit this section of Alaska. ecause of improved access, the burgeoning human population of the Nation, the growing nterest in angling, and availability of more leisure time, it is expected that sport ishing for resident fish of the Yukon basin would increase significantly. During he period of analysis, an average of 20,000 man-days of sport fishing for resident ish would be expended each year without the project.

ith the project, Rampart Reservoir would greatly expand coldwater fish habitat and t is believed that fish populations similar to those of existing large, cold natural akes, such as Great Slave Lake of Canada, would ultimately develop. Such lakes are minated typically by lake trout and whitefish with northern pike and sheefish ccurring in lesser abundance. Lake trout are virtually absent from the reservoir ite at present and it would require a long period of time for significant populations o develop in the reservoir. Lake trout, however, could be expected to assume domiance in the reservoir fish population after a period of many years. The large expanse of open water in the Rampart impoundment could deter sport fishing activity to ome extent since the use of large seaworthy boats would be required. The sporting ualities of lake trout, however, and the accessibility of large bays along the horeline would ultimately encourage recreational fishing. These factors coupled ith the increasing proportion of anglers in the human population and the growing nterest in outdoor recreation, would assure a high demand for sport fishing in the eservoir. The time required for reservoir filling and growth of fish populations, owever, would severely retard full development of a sport fishery.

ver the 100-year period of analysis, it is estimated that sport fishing in the eservoir would average 40,000 angler-days annually. In addition to sport fishing in ne reservoir area it is expected that the ecology of the Yukon River downstream from ampart Dam to the mouth of Tanana River, a distance of about 40 miles, would be ltered and that populations of resident fish would develop here. Sport fishing in nis area would amount to an estimated average annual use of 20,000 angler-days. This se combined with the increased use expected in the reservoir would total 60,000 ngler-days of fishing annually, or a net increase of 40,000 angler-days over conditions without the project. The total benefit to sport fishing with the project, ased on this increased use is valued at $60,000 annually.

It is difficult to predict how the subsistence fishery of the reservoir area would be affected by project development. Native residents of the area would be displaced and their mode of living could be expected to change considerably. A fishery in the reservoir would develop slowly. If residents of the area continue to live near the reservoir after project construction, they would need to learn and adapt to new fishery methods. They would be unable to catch enough fish for their own needs during the first one-third of the period of analysis. Only after the reservoir has filled and the fish populations have expanded would subsistence fishing be feasible. Thereafter, fish production in the reservoir would be more than adequate to fulfill subsistence demand of the native people in the area.

Rampart Reservoir would provide a commercial fishery of moderate value during the latter part of the period of project analysis. Fish production in the reservoir would be similar to that found in certain large, cold, natural lakes located at similar northern latitudes. Some of these lakes, however, sustain commercial fisheries. Development of a successful commercial fishery in the reservoir would be impeded by several factors such as: (1) the difficulty in using sinking gill nets because of standing vegetation on the bottom; (2) the distance to major population centers; and (3) the high cost of harvesting and processing. Harvest of whitefish could not begin until 35 to 50 years after initiation of project construction and harvest of lake trout would not be possible for many years thereafter. On the average over the 100-year period of analysis the reservoir would provide a commercial harvest of resident fish of about 3.6 million pounds annually. This new commercial fishery for resident fish would compensate only in part for the losses which would be suffered by the commercial fishery for anadromous fish if Rampart Dam is constructed. Furthermore, it could not provide a subsistence fishery for residents along hundreds of miles of rivers, both upstream and downstream from the project.

WILDLIFE RESOURCES AND PROJECT EFFECTS

The vast area that would be inundated by the project encompasses the Yukon Flats which contains some of the most productive waterfowl breeding habitat in North America. The area also provides habitat for significant numbers of big game, small game, and fur animals.

Waterfowl

It is upon waterfowl that the Rampart Canyon project would have the most significant adverse effects. Somewhat more than 36,000 lakes and ponds totaling about 760,000 acres are contained within the 10,500 square-mile impoundment site. These waters are exceptionally well interspersed with the land areas. Such interspersion creates an outstanding waterfowl production unit of about 7,000,000 acres. Currently, the Yukon Flats (impoundment area) provides prime waterfowl habitat that is heavily used from the breakup in April or May until freezeup in October. Migrant ducks and geese use the area for resting and feeding, but the greatest importance of the Flats to waterfowl is for nesting and rearing of young. Approximately 2,400,000 acres of the area are regarded as high-density duck breeding habitat. The remaining portion of somewhat lower productivity per unit area, also produces large numbers of ducks because of its vast size. The half million breeding ducks that raise their young on the Yukon Flats represent about 1.6 percent of the total continental breeding population which has averaged about 32,000,000 birds for the period 1950-1962, inclusive.

is superb nesting habitat would be expected to contribute annually about 1,500,000 ucks, 12,500 geese, and 10,000 little brown cranes to Canada and all four waterfowl lyways in the United States under conditions without the project. This contribution s expected to increase in importance, for despite the waterfowl habitat preservation rograms presently pursued by various fish and game interests, losses of nesting abitat in the prairies of north-central United States are expected to continue. imilar losses are expected to occur in the prairie provinces of Canada and in other reas as civilization advances. The current long-range waterfowl management program f the U.S. Fish and Wildlife Service envisions the acquisition of about 3,720,000 cres with funds available to the Migratory Bird Conservation Account. Of this total rea, small waterfowl production areas comprise about 1,750,000 acres. This acreage ompares with the 2,400,000 acres of high density waterfowl breeding habitat that ould be inundated by the project.

aterfowl produced on Yukon Flats, without project development, would supply an verage annual total of 300,000 man-days of duck hunting and 25,000 man-days of goose unting in the United States and Canada during the period of project analysis. Con- truction and operation of the project would completely destroy this valuable and nique waterfowl production area.

he fluctuating reservoir would have steep, wave-washed shorelines which would preclude ormation of marshes suitable for nesting or shallow waters productive of waterfowl oods. Waterfowl habitat would not develop in other areas adjacent to the reservoir. he large expanse of open water would provide no nesting habitat. Migrating waterfowl ould use the large, open waters of the reservoir as a resting area in autumn; owever, lack of food producing areas would severely restrict such use. The reservoir ould be ice covered at the time spring migrating waterfowl arrive so birds would not se the reservoir at that time. The project would not provide agricultural or wetland aterfowl habitat such as that created at water development projects in the Columbia iver basin. Project plans do not include irrigation systems which would encourage evelopment of seep areas or marshes that have been particularly attractive to mi- rating and wintering waterfowl in the western conterminous states.

verflow areas which presently provide waterfowl breeding habitat downstream from the amsite would be reduced in area and productivity by control of flooding which the roject would provide. Waterfowl production in these areas would be lowered but these osses, though substantial, would not be large in comparison with those that would be ustained on the Yukon Flats. Waterfowl that would return to ancestral breeding rounds on the Yukon Flats during the reservoir filling period would have to seek other esting areas. Many of these alternate nesting areas, which already are used to apacity, would become overcrowded. Flood [sic] supplies would be inadequate to upport increased numbers of waterfowl. Competition for space would be increased eyond the tolerance of these birds. Their needs for space during the breeding and esting seasons could not be met and production beyond that which presently occurs in hese areas could not be sustained.

her Wildlife

g-game animals of the area are moose, black and grizzly bears, and caribou. The eservoir area provides high-quality winter range for a moose herd estimated to number bout 5,000 animals. About 320 animals are harvested annually by residents for food. he carrying capacity of the area for moose, however, exceeds present use and it is stimated that the Flats within the reservoir site would ultimately support 12,500 oose.

Muskrats, minks, beavers, and river otters are the most common aquatic fur animals in the area. Terrestrial fur animals include martens, wolverines, weasels, lynxes, snowshoe hares, red foxes, and red squirrels. The annual value of the fur-animal harvest is estimated at 41,000 pelts or about 7 percent of the entire Alaska fur harvest. Several species of grouse and willow ptarmigans are present in the impoundment area. These receive light hunting pressure.

With the project, the productive moose range of the Yukon Flats would be inundated and completely destroyed. The habitat for bears would be eliminated. Displaced moose and bear populations would not be sustained on the lands surrounding the reservoir because such habitat would be supporting these species at carrying capacity.

The habitat for fur animals as well as grouse and ptarmigans would be eliminated. Populations of these animals would be eliminated because the habitat around the margins of the reservoir would be fully used by these same species. Caribou would be little affected by the project.

DISCUSSION

The effects which construction and operation of Rampart Canyon project would have on the valuable fish and wildlife resources of the Yukon River basin have been determined. The enormity of the losses to anadromous fish and to waterfowl is of great concern to this Service. Nowhere in the history of water development in North America have the fish and wildlife losses anticipated to result from a single project been so overwhelming. The effects of the project on anadromous fish would be felt not only in the State of Alaska but in Canada. The losses to waterfowl populations would be evident in the United States, Canada, and Mexico. The United States is bound by treaty with these nations to protect mutual interests where these migratory birds are concerned and is obligated to preserve these resources.

Measures have been sought which would reduce or alleviate the adverse effects this project would impose on fish and wildlife resources of the Yukon River basin. Investigations have been made of the possibility of passing anadromous fish around the dam and the reservoir. There are no known means which would assure successful fish passage at this vast Arctic project. The possibilities for trapping upstream migrants, transporting them through the reservoir on barges and subsequently collecting downstream migrants at the mouth of each major tributary and transporting them to the river downstream from the dam have been studied. Such facilities would be extremely costly and it is doubtful that these valuable fish could be maintained in this way. Handling of fish during the transporting phases would be difficult and reservoir ice conditions most likely would render the entire plan infeasible. The possibility of relocating anadromous fish runs in other streams in the area has been considered; however, it is improbable that areas adequate for relocation of the runs exist in the Yukon Basin downstream from the damsite. After analyzing the possible solutions for mitigating or preventing losses to anadromous fish runs, it has been concluded that artificial production facilities located downstream from the dam would be the most feasible way to sustain at least a portion of these fish runs. Complete success of artificial production cannot be assured because such a program has never been attempted under Arctic conditions.

ilot facilities capable of handling a portion of the runs would be required to rovide the information necessary for appraisal of the cost and practicability of uch measures under Arctic conditions. Pilot studies to determine measures for im- roving natural spawning habitat downstream from the dam and of relocating segments of he anadromous fish run should also be undertaken. If the project is authorized, ilot facilities should be built and studies initiated at the earliest possible time. rom the initiation of dam construction, only six to seven years would be available or pilot studies, evaluation, and design and construction of production facilities apable of accommodating the entire run. The extremely limited time available would ermit only a determination of the feasibility of conducting these operations under rctic conditions. Determination of the success of such programs could not be ini- iated before the return of adult fish produced by these operations. Total estimated ost of the pilot production facilities and the studies would be $30.1 million. nnual cost of operation and maintenance of pilot facilities would be $1.5 million.

tudies may reveal that a combination of several methods would be the most reasonable ay to sustain the salmon runs. After completion of the studies, a detailed develop- ent report would be prepared to describe the most feasible program for the conser- ation of salmon resources. Production facilities necessary for such a program would st an estimated $170 million. Ultimate annual operation and maintenance of such roduction facilities would cost $7.1 million.

emporary fish passage facilities would be needed at the dam during project construc- ion to pass fish for about 6 years as long as it would be biologically feasible to do . Estimated cost of these facilities would be $20 million. Maintenance and opera- ion of the facilities during the construction period would cost $1 million annually. f a major break-through in the science of fish passage should occur in the interim eriod, passage of fish around Rampart Dam and Reservoir might prove to be a more easible means of conserving Yukon River salmon than the production facilities escribed above.

e fishery for resident fish expected to develop in Rampart Reservoir would take many ears to evolve. To hasten and direct the development of this reservoir fish popula- ion it would be necessary to introduce stocks of lake trout and perhaps other species. ese fish would be stocked during the reservoir filling period. Successful stocking f the reservoir would require a prior program of study to develop optimum techniques d to consider other species and races for stocking. Later, studies of the developing sh populations would be needed to determine the most effective stocking and manage- ent programs. Cost of these studies would be about $400,000. The estimated cost of tchery and rearing facilities to produce the stocks would be $10 million. The stimated cost of annual operation and maintenance during the reservoir filling period uld be $900,000.

udies have revealed that there are no feasible means to compensate fully for the emendous losses of wildlife resources caused by the project. There are no apparent ecific means to replace losses of big-game and fur-animal habitat. Small-game bitat lost through project development likewise would be irreplaceable.

search for methods to mitigate losses of waterfowl habitat, consideration was given the possibilities of acquiring and developing waterfowl areas, of the magnitude quired, in the conterminous United States and in Canada. Many problems, however, ke this infeasible. In particular, lands best suited for development in these areas are already needed to replace habitat losses resulting from the advancement of intensive land-use practices. No surplus capacity is available for mitigation of losses that would result from the Rampart project. In addition, development of habitat in these areas would not provide the same species composition that is produced in the Yukon Flats area nor would the birds follow a comparable migration pattern. Artificial production of waterfowl also was considered to replace birds which would be lost as a result of project construction. At the present time, this method appears infeasible because of high costs, uncertain results, and other factors. If new techniques for artificial propagation of waterfowl become available, further consideration would be warranted.

Surveys of central Alaska have revealed some tracts of existing waterfowl habitat which could be improved by development and management to increase waterfowl production. Such development would also improve suitability of the habitat for fur animals and moose. We have delineated areas which would give the greatest return per dollar spent and have found that it appears biologically feasible to improve production sufficiently to offset about 20 percent of the project-occasioned waterfowl losses. Pilot habitat improvement studies would be conducted initially on relatively small tracts so as to develop and improve techniques of management to increase production to the highest possible levels at the least cost. On the basis of these studies habitat development reports would be prepared, describing in detail the cost and effectiveness of proposed large-scale developments. Pilot habitat improvements and studies would cost about $50 million. It is presently estimated that an additional $300 million would be required for ultimate development of the waterfowl production habitat. Estimated annual costs of operating and maintaining the total waterfowl area would be $1 million when fully developed.

SUMMARY AND CONCLUSIONS

The preceding discussion has briefly described mitigation measures which could be undertaken to offset some of the losses fish and wildlife would suffer if Rampart Canyon project were constructed. It would be difficult to maintain the runs of salmon now passing the damsite. Determination of the most desirable method would require detailed studies. Any facilities or means which would help sustain the salmon runs would be extremely costly. No means or measures are apparent that could, in any way, mitigate the losses of the subsistence fishery which is a basic need of residents in the area upstream from the damsite. The salmon fisheries which presently exist in the Yukon River drainage of Canada would be lost. The degree to which the measures would offset losses to other salmon fisheries is difficult to assess. It is believed, however, that a portion of the run could be perpetuated. It appears that fisheries would ultimately develop in the reservoir but maximum development of the resident fish potential would require stocking of lake trout and could only be accomplished at a considerable cost and over a period of many years.

Big-game, fur-animals, and small-game populations of the reservoir area would be lost. It would be infeasible to provide substitute habitat specifically for these animals. A habitat development program for the waterfowl resource could be undertaken that would compensate for about 20 percent of the waterfowl losses.

etailed studies, particularly of operational pilot facilities, would be necessary to etermine the feasibility and costs of the final conservation measures considered. he costs of such studies and pilot facilities would total $80.5 million and are isted in the table below.

	Pilot Facilities and Studies (Millions)	Annual Operation and Maintenance (Millions)
nadromous Fish	$30.1	$1.5
esident Fish	.4	-0-
ildlife	50.0	-0-
	$80.5	$1.5

e results of these studies would provide a basis for later recommendations to the ecretary of the Interior for the implementation of feasible measures. Based on esent knowledge, the maximum cost of this large scale effort would be $500 million. sts of the component measures are shown in the following table.

	Capital Expenditures (Millions)	Annual Operation and Maintenance (Millions)
adromous Fish	$190	$ 8.1
sident Fish	10	0.9
ldlife	300	1.0
	$500	$10.0

o measure would be recommended until its feasibility had been clearly demonstrated by udies of pilot facility operations. Thus, the $500 million sum represents the ximum amount which might be expended for provision of measures to mitigate fish and ldlife losses.

implemented, these measures would replace only a portion of the losses caused by e project. The uncompensated losses would be substantial. The degree of success of e mitigation measures cannot be foretold at this time. Accordingly, we strongly pose authorization of the Rampart Canyon Dam and Reservoir project.

COMMENDATIONS

is recommended:

) That Rampart Canyon Dam and Reservoir project not be authorized for construction.

) That, if construction of the project is authorized, the following recommendations included in such authorization:

(a) Additional detailed studies of fish and wildlife resources be conducted, as necessary, after the project is authorized, in accordance with Section 2 of the Fish and Wildlife Coordination Act; and that such reasonable modifications be made in the authorized project facilities as may be agreed upon by the Secretary of the Interior and the Secretary of the Army, for the conservation, improvement, and development of these resources.

(b) Project funds in the amount of $80.5 million for studies and construction of pilot facilities and $1.5 million for annual operation and maintenance of these facilities be made available to the Secretary of the Interior at the time of authorization for development of the most effective means and measures for the mitigation of fish and wildlife losses.

(c) Project funds in the amount of $500 million for capital expenditures be authorized for appropriation to the Secretary of the Interior, as required, for the ultimate implementation of measures to mitigate losses to fish and wildlife resources, and that $10 million be made available annually during the life of the project for the operation and maintenance of these measures.

S/ J. T. Barnaby

Acting Regional Director
Bureau of Sport Fisheries and Wildlife

S/ Harry L. Rietze

Regional Director
Bureau of Commercial Fisheries

ALASKA CONSERVATION SOCIETY
Box 192, College, Alaska

PRESS RELEASE

Dated May 11, 1964

Dr. Frederick C. Dean, of College, Alaska, was elected President of the Alaska Conservation Society at the annual meeting of the Board of Directors, held Saturday evening at the home of Dr. and Mrs. David Klein, Yankovitch Road. Mr. Daniel Swift, Hamilton Acres, was chosen for the Vice Presidential post, and two incumbent officers were re-elected: Mrs. Nancy Simmerman, Treasurer, and Miss Celia M. Hunter, Secretary.

This is the fourth year of operation for the Alaska Conservation Society, which has a membership of over 400, including both regular Alaskan members and associates from outside the state. The Society publishes a quarterly News Bulletin, edited by Dr. Robert B. Weeden. Mrs. William Nordmark is the current membership chairman for the group.

A recent election added three new members to the Society's Board of Directors. They were Dr. David Klein, Dr. William O. Pruitt, and Dr. Frederick C. Dean. They joined incumbent Board members Mrs. Virginia Hill Wood (retiring President), Dr. Richard A. Cooley, of Juneau, and Dr. Robert Rausch, of Anchorage.

The Alaska Conservation Society is a non-profit corporation formed to secure the wise use, protection, and preservation of the scenic, scientific, recreational, wildlife and wilderness values of Alaska Membership is open to all persons who share these concerns, and requests for information and applications may be obtained by writing the Society, c/o Box 192, College, Alaska.

30 30 30 30 30 30 30 30 30

18425 Pam:627.8:(*493)
USDI

U.S. Dept. of the Interior. Fish
and Wildlife Service.
Effects of proposed Rampart
Canyon Dam and Reservoir project,
Yukon

DATE LOANED	BORROWER'S NAME	DATE DUE

18

BO
THE
EDM
CAN

IRARY

18425 Pam:627.8:(*493)
USDI

U.S. Dept. of the Interior. Fish
and Wildlife Service.
Effects of proposed Rampart
Canyon Dam and Reservoir project,
Yukon

Boreal Institute for Northern
Studies Library
CW 401 Bio Sci Bldg
The University of Alberta
Edmonton, AB Canada T6G 2E9

University of Alberta Library
0 1620 0335 9898

Univ. of Alberta
Boreal Institute
Edmonton, Alberta
CANADA

BP-138E

POTENTIAL ENVIRONMENTAL EFFECTS OF THE PROPOSED JAMES BAY DIVERSION PROJECT (GRAND CANAL)

Robert J. Milko

Science and Technology Division
Research Branch
Ottawa

17 September 1985

LIBRARY OF PARLIAMENT

POLAR
PAM
4589

POLARPAM

POTENTIAL ENVIRONMENTAL EFFECTS OF THE PROPOSED JAMES BAY DIVERSION PROJECT (GRAND CANAL)

Robert J. Milko

Science and Technology Division
Research Branch
Ottawa

17 September 1985

BACKGROUND PAPER FOR PARLIAMENTARIANS

di DEC 11 1987
er No. 19070A
$4.00
No. Supply & Services.

BOREAL INSTITUTE
LIBRARY

© Minister of Supply and Services Canada 1987

Cat. No. YM32-2/138E

ISBN 0-660-12431-9

TABLE OF CONTENTS

Page

INTRODUCTION 1

GENERAL DESCRIPTION 2

A. Circulation 2

B. Salinity, Temperature and Seasonal Distributions 3

C. Freshwater Input 7

BASIC PRINCIPLES AND EFFECTS OF FRESHWATER FLOW 9

POTENTIAL EFFECTS OF CHANGES TO HUDSON BAY 14

A. Ice Pack and Climate 14

B. Primary Productivity 15

C. Aquatic Food Chain 18
1. Plankton and Macrobenthic Fauna 18
2. Fish 19
3. Mammals 20

D. Waterfowl, Shorebirds and Seabirds 24
1. Waterfowl 24
2. Shorebirds 25
3. Seabirds 25

ADDITIONAL EFFECTS AND CONCERNS 25

DISCUSSION 27

CANADA

LIBRARY OF PARLIAMENT
BIBLIOTHÈQUE DU PARLEMENT

POTENTIAL ENVIRONMENTAL EFFECTS OF THE PROPOSED JAMES BAY DIVERSION PROJECT (GRAND CANAL)

INTRODUCTION

The Hudson Bay drainage area includes more than three million square kilometres, has an annual average discharge rate more than twice that of either the Mackenzie or St. Lawrence Rivers, and contains the largest body of water in the world that virtually freezes over each winter and becomes ice-free during the summer; yet it has been only marginally studied.(1,2) In the 1970s, hydroelectric developments on rivers which flow into James Bay prompted an increase in studies of James and Hudson Bays with research predominantly focused on James Bay. It is from this scant information that predictions of the effects of terminating the flow of freshwater from James Bay into Hudson Bay must be made.

In view of the resurgence of interest in the "GRAND Canal" scheme,(3) which would involve the construction of a dam across James Bay,(4) an assessment of potential impacts warrants attention. In order to speculate on these impacts, the oceanographic parameters of Hudson and

---

(1) Average annual discharge rate of Hudson Bay drainage area is 22,600 cubic meters per second (m^3/s).

(2) S.J. Prinsenberg, "Man-Made Changes in the Freshwater Input Rates of Hudson and James Bays," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 37, 1980, p. 1102.

(3) GRAND is an acronym for "Great Recycling and Northern Development."

(4) Robert Bourassa, Power from the North, Prentice Hall, New Jersey, 1985, p. 133-157.

James Bay must first be understood. Consequently, this report first briefly summarizes some of these parameters, with an emphasis on those of Hudson Bay. Second, the report examines some similar, large-scale diversions elsewhere, which should help to illustrate the effects or potential effects of large-scale water diversions. Thirdly, possible impacts on the oceanographic and ecological parameters of Hudson Bay and James Bay, resulting from the construction of a dam which would terminate the flow of freshwater between these bodies of water, are examined.

GENERAL DESCRIPTION

Hudson Bay is part of a large inland sea which is connected to the Atlantic Ocean by Hudson Strait and the Labrador Sea, and, to the Arctic Ocean by Fury and Hecla Strait. Hudson Bay has an average depth of 125 m and an approximate rectangular shape of 925 by 700 km. James Bay is much shallower, seldom deeper than 50 m, and with an average depth of 28 m; it is 150 km wide and 400 km long.

A. Circulation

Hudson Bay has generally been believed to behave as a huge estuarine basin with fresher, less dense water flowing out at the surface and denser, saltwater moving in at depth.(1) Because of sills and varying depths at the entrance to Hudson Bay, deepwater exchange appears to occur predominantly by way of one central channel, with some winter influx by way of a shallower channel to the north and west of Southampton Island. Saltwater inflow into Hudson Bay through these two channels has been estimated at 0.5×10^6 m^3/s and 0.05 to 0.1×10^6 m^3/s, respectively.(2) The water that enters the bay is heavier and sinks elow the surface layer and does not show up as surface flow.(1)

---

(1) R.J. Pett and J.C. Roff, "Some Observations and Deductions Concerning the Deep Waters of Hudson Bay", Le Naturaliste canadien, Vol. 109, 1982, p. 767.

(2) M.J. Dunbar, "Oceanographic Research in Hudson and James Bays," Le Naturaliste canadien, Vol. 109, 1982, p. 680.

Figure 1 shows the summer surface circulation pattern of udson and James Bays. In Hudson Bay, the southeasterly surface circulation s predominantly wind-driven in the summer and autumn, resulting in a yclonic pattern with an average speed of 5 cm/s. The circulation is also artially driven by density currents as a result of dilution because of reshwater runoff. Surface outflow is predominantly through Hudson Strait o the north (9 cm/s) and is seasonal in response to the freshwater input ycle. The absence of a northwestward return flow results in an upwelling egion along the northwestern shore where deeper water partially replaces he offshore component of the surface flow to the southeast.

Circulation in James Bay is comprised of a cyclonic gyre, riven partly by wind stress and by runoff dilution. This also results in n estuarine circulation where cold saline water enters James Bay from udson Bay beneath the fresher surface layer(2) and exits in a strong ortherly, surface outflow (15 cm/s in the summer) along the eastern shore nto Hudson Bay.

B. Salinity, Temperature and Seasonal Distributions

Data in all seasons for Hudson Bay are lacking but are omewhat more complete for James Bay. Generally, the less saline water is ound along the south and east shores of Hudson Bay,(3) and unlike the ase in Hudson Strait, a temperature increase at large salinities associated ith a deep layer of Atlantic water, is not found. Cross-sectional surveys ave indicated that below the surface layer the water continually becomes older

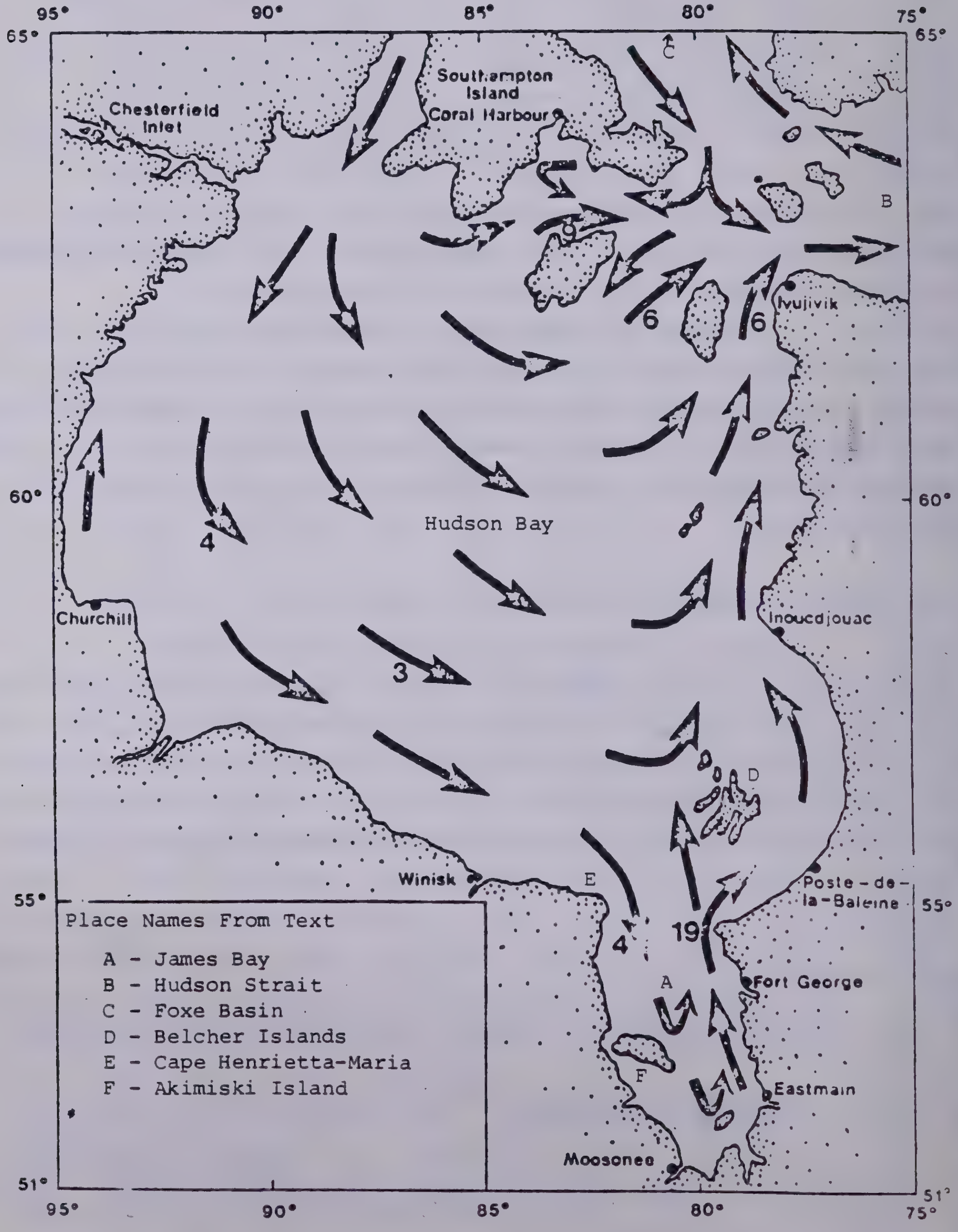
---

(1) S.J. Prinsenberg, "Circulation Pattern and Current Structure of Hudson Bay," Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

(2) Ibid., p. 1-11 of draft copy.

(3) S.J. Prinsenberg, "Time Variability of Physical Oceanographic Parameters in Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 686.

FIGURE 1: SUMMER SURFACE CIRCULATION PATTERN OF HUDSON BAY



Source: S.J. Prinsenberg, "Circulation Pattern and Current Structure of Hudson Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press September 1985).

and more saline with depth. At 100 m, the water has an average salinity greater than 33‰(1) and is colder than -1.4°C. Offshore salinities of major rivers in James Bay can be as low as 10‰ with the lowest salinities occurring in the summer because of increased runoff and melting of the ice cover.(2)

A simple description of circulation involving these parameters can be envisioned as cold subsurface water with a salinity greater than 30‰ entering Hudson Bay from Hudson Strait, while the surface water, moving north along the eastern shore is a water mass warmed by solar radiation and diluted by runoff. The outflow temperature and salinity are somewhat modified by vertical mixing with the subsurface waters as they circulate through Hudson Bay.

Although insufficient data are available to accurately model seasonal variations of salinity and temperature, some general observations can be made. The pycnocline,(3) established in conjunction with surface runoff in the spring, progresses to greater depths as the season advances, reaching a maximum depth of 93.5 m at the end of the following winter (Figure 2). Below the pycnocline (average depth of 25 m) water properties remain relatively constant but, above the pycnocline, vertical mixing redistributes solar input to produce a relatively homogeneous water temperature which contains 74% of the total heat input to the bay.(4)

---

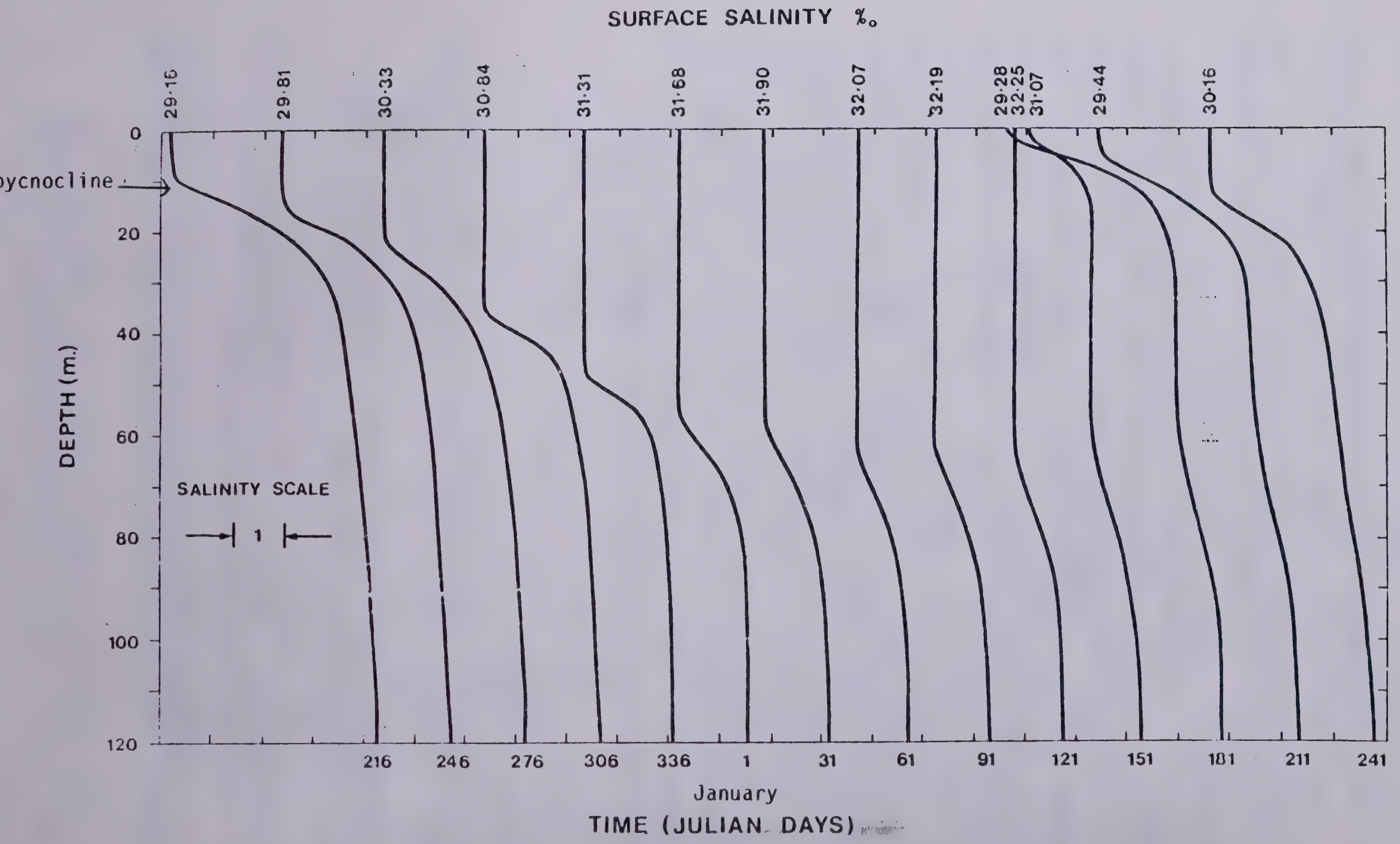
(1) Note: ‰ means parts per thousand -- Atlantic Ocean surface water has an average salinity of 30‰. Sea ice has an average salinity of 5‰.

(2) S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay," Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

(3) Pycnocline may be defined as a sharp boundary separating two liquid layers of different densities, e.g., a freshwater layer over a saltwater layer with little diffusion between them.

(4) S.J. Prinsenberg, "Freshwater Contents and Heat Budgets of James Bay and Hudson Bay," Continental Shelf Research, Vol. 3, No. 2, 1984, p. 198.

FIGURE 2: MODELLED SALINITY PROFILES OF HUDSON BAY AT A THIRTY-DAY TIME INTERVAL OVER A ONE-YEAR PERIOD



Source: S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

C. Freshwater Input(1)

Because ice is relatively fresh (5‰), ice cover and runoff have been calculated to be major and equal components of the freshwater flux of Hudson Bay. Their individual contributions are described below.

In Hudson Bay the ice cover starts to form in northern areas by late October and continues to grow until a maximum cover is reached at the end of April. An average ice thickness of 1.75 m is found in southern James Bay but an average of only 1 m is found in northwest Hudson Bay. Polynyas (open water leads in the ice) are found predominantly along the northwest coast and east coast of Hudson Bay, both coasts of James Bay and west of the Belcher Islands joining the two mainland masses.(2)

Decay of the ice cover commences in late May, rapidly releasing this source of stored freshwater throughout June and July. Breakup in Hudson Bay, aided by predominant northwest winds, occurs from north to south and east to west. Although this fresh water addition from the melting ice is approximately equal in volume to that of runoff and will contribute to the estuarine cyclonic circulation of Hudson Bay, it would appear to have no net effect on the overall salinity of the bay. It does, however, contribute as much to the water column stability induced by the upper fresh water layer, as does the surface runoff.

In contrast to Hudson Bay, the ice of James Bay breaks up from south to north with the bay usually ice free by the end of July. The timing and pattern for James Bay's breakup is strongly dependent upon the large quantity of relatively warm, freshwater of the spring runoff.(3) Consequently, this surface outflow from James Bay initiates the early breakup of the ice in south east Hudson Bay.

Runoff is a function of both spring melt and precipitation. In Hudson Bay the mean runoff per unit drainage area increases from north to south with a maximum value in south James Bay. On a seasonal basis, a maxi-

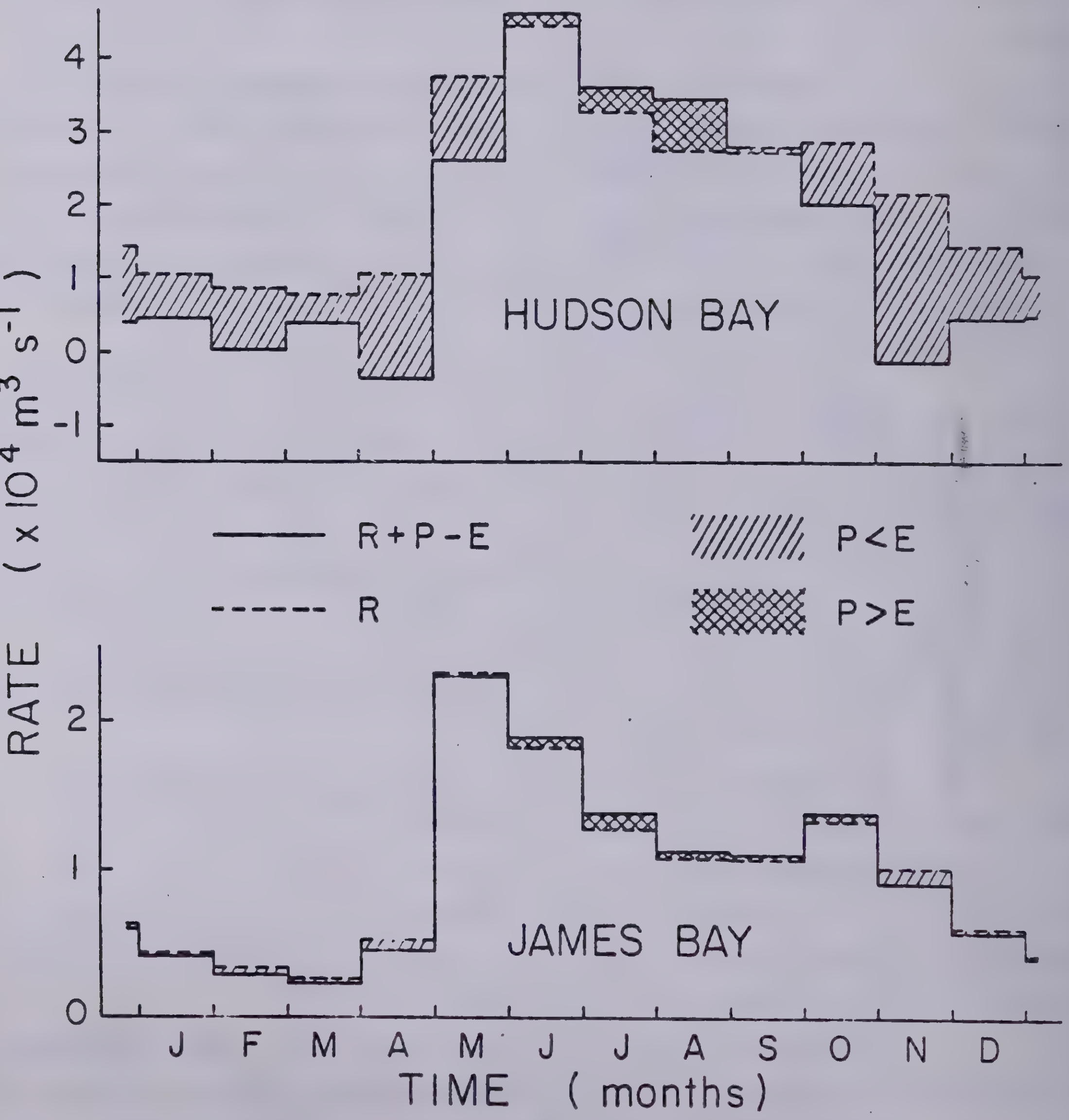
---

(1) Prinsenberg (1985), "Salinity and Temperature Distributions of Hudson Bay and James Bay", p. 7-18 (for this section unless otherwise cited).

(2) Energy, Mines and Resources Canada, The National Atlas of Canada, Macmillan Company of Canada Ltd., Ottawa, 1974, p. 13.

(3) Prinsenberg (1980), p. 1104.

FIGURE 3: SEASONAL RUNOFF CYCLES FOR HUDSON BAY AND JAMES BAY



Note: R = Runoff
P = Precipitation
E = Evaporation

Source: S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press September 1985).

mum runoff for both bays occurs with the spring freshet of May and June (Figure 3). In James Bay, however, a secondary peak of runoff occurs during the pronounced rainy season of the southern region. Here the precipitation rates are nearly double those of Hudson Bay and balance the loss of water resulting from evaporation. In contrast, Hudson Bay acts more as an oceanic region and loses more in evaporation than it gains from precipitation.

In summary, freshwater input cycles calculated from runoff, precipitation and evaporation can be divided into a winter and summer season. During the summer, the entire surface area of both bays gains a 10 cm layer of freshwater per month, which decreases to a 0.5 cm layer during the winter. Over the year, the region receives a 64 cm layer of freshwater (5.23×10^{11} m^3) which is equal to 0.5% of its total volume. Of this, James Bay accounts for 61% (3.17×10^{11} m^3), which indicates its importance to the freshwater budget of Hudson Bay.

The heat budget shows that the ice cover and the water column are the main benefactors of the incoming surface heat flux, and, that heat is lost mainly to turbulent fluxes which are very sensitive to the stability of the atmosphere. The results of the freshwater and heat budget show that the annual ice cover, runoff and heat content of the surface water are closely related. Changes in one will affect the others.

BASIC PRINCIPLES AND EFFECTS OF FRESHWATER FLOW

A primary reason for estuaries, embayments and continental shelves being fertile, productive regions is the supply of freshwater from land runoff which deposits nutrients directly and which, on entering the ocean, induces mixing and the entrainment of nutrient-rich deepwater to the surface. Particularly in higher latitudes, nearshore biological processes and adjacent ocean activities are attuned to this massive, seasonal influx. A freshwater flow encountering saltwater results in the formation of a density current or haline circulation system such as that which helps to drive the estuarine circulation of Hudson Bay. The effect of a density current is to impose a two-layer flow system which, in an estuary, causes the surface layer of freshwater to flow outward and the deeper (often nutrient-rich) bottom saltwater to flow inward. The magnitude of the current will of course be proportional to the pressure difference and in an unregulated system, pulses of current occur as a result of seasonal runoff. It is possible that a reduction of a density current could result in a reduction in productivity.

An example is that of the St. Lawrence River and the Scotian Shelf and Grand Banks (Figure 4). The density current from the St. Lawrence freshwater flow results in deepwater from the continental shelf penetrating more than 1,500 km upstream without any significant contact with the freshwater. Over large distances as to the Grand Banks, there can be delays from several months to a year before a freshwater peak arrives. Regulation of the St. Lawrence River via the Manicougan-Outardes-Bersimis hydroelectric power complex commenced in the 1960s and retained up to 8,000 m^3/s by the spring of 1970 (one-quarter to one-third of the peak discharge of the St. Lawrence). This resulted in an approximate 1.3‰ increase in summer salinity of the surface layer at Cabot Strait and a drastic reduction in cyclic (seasonal) variation of salinities when compared to the unregulated condition.(1,2) Neu contends that this storage scheme had and continues to have an impact on the biological resources of the Atlantic coastal region. He estimates a 20-30% reduction of nutrients entering the system during the biologically active period and illustrates the relationship between varying flow rates and fish stocks, i.e., the larger the runoff, the greater the yield.(3,4,5) Data to prove the effect are admittedly masked by other possibilities such as changes in fishing levels.

---

(1) H.J.A. Neu, "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part I," Marine Pollution Bulletin, Vol. 13, No. 1, January 1982, p. 7-12.

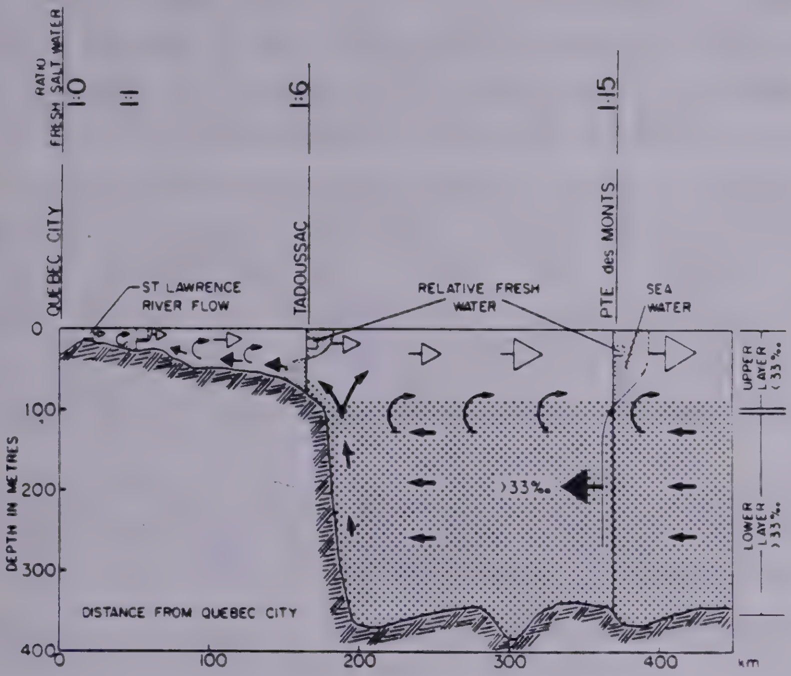
(2) H.J.A. Neu, "Runoff Regulation for Hydro-Power and its Effect on the Ocean Environment", Hydrological Sciences Bulletin, Vol. 21, No. 3, September 1976, p. 433-444.

(3) *Ibid.*

(4) H.J.A. Neu, "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part II," Marine Pollution Bulletin, Vol. 13, No. 2, February 1982, p. 44-47.

(5) Neu (1982), Part I, p. 12.

FIGURE 4: SCHEMATIC REPRESENTATION OF HALINE CIRCULATION (DENSITY CURRENT) IN THE ST. LAWRENCE RIVER SYSTEM



Source: H.J.A. Neu, "Runoff Regulation for Hydropower and its Effects on the Ocean Environment", Canadian Journal of Civil Engineering, Vol. 2, No. 4, 1975, p. 588.

Considerable concern has been expressed about possible climate modification as a result of large-scale water diversions of north-flowing rivers. In particular, plans of the U.S.S.R. to divert water from rivers flowing into the Arctic have led to some research into the impact of a reduction in the natural discharge on Arctic sea ice. Current water transfer proposals, scheduled to commence in 1986(1) involve the withdrawal of 60 km^3/yr from the European-north of the U.S.S.R. and 60 km^3/yr from the Siberian region, with a possible additional withdrawal of up to 100 km^3/yr during the 21st century. Because sea-ice concentration data for the Arctic and its marginal seas correlate significantly with variations in discharges of Siberian rivers, several mechanisms affecting localized and large-scale sea-ice cover are worthy of investigation. The first three of five mechanisms involve local or regional impacts:(2)

1) A reduction in riverflow could result in delayed removal of fast ice(3) or a reduction in removal of broken fast ice.

2) Reduced heat influx, i.e., warm freshwater, could result in early ice formation in the autumn.

3) A reduction of freshwater could result in a higher salinity which could lead to delayed or reduced ice formation in the autumn.

Hypotheses concerning mechanisms which have large-scale effects are more complex. Two are outlined below:

4) Density gradients (described earlier) result in an inflow of warm Atlantic water which, because of its high salinity (density), sinks below the colder, less dense Arctic water. The halocline in this Arctic region functions as a marked pycnocline and forms a barrier which suppresses heat flow from the deep Atlantic water

---

(1) P.P. Micklin, "The Vast Diversion of Soviet Rivers," Environment, Vol. 27, No. 2, March 1985, p. 13.

(2) T. Holt et al., "Cryospheric Impacts of Soviet River Diversion Schemes," Annals of Glaciology, Vol. 5, 1984, p. 61-68.

(3) Fast ice was water adjacent to the shore that is now frozen throughout its depth.

to the surface. It has been suggested that a reduction in riverflow could lead to a subsequent thinning of the pycnocline allowing the deep, warm Atlantic layer to reach the surface. This could result in large ice-free areas and a general warming trend.

5) Conversely, less freshwater outflow could produce a weaker density current, reducing the strength of warm inflow from the Atlantic. This might result in colder overall temperatures and an increase in ice cover.

Modelling of the river flows and ice pack conditions suggests that a reduction of river discharges could result in local increases of ice in some areas and decreases of ice in others. On a large scale, modelling of mechanism 5) (above) suggests a reduced density current and an increase of ice cover are possible; mechanism 4) (above) could not be similarly modelled because of a lack of empirical data.

A numerical model, examining these diversions in the U.S.S.R., suggests some erosion of the stable stratification in the Kara and Barents Seas but not to the point of convective instability. As well, little change in the extent of sea ice, except for possible local minor thickening was predicted.(1)

Opinion is divided over whether the gross effects would be an overall warming or cooling, two diametrically opposed results; however, the weight of opinion and evidence points to a cooler Arctic.(2,3) If, however, a decreased ice pack was a result, it has been suggested that this, coupled with the greenhouse effect, could reduce rainfall in the very areas expecting to benefit from the diversions.(4,5)

---

(1) A.J. Semtner, "The Climatic Response of the Arctic Ocean to Soviet River Diversions," Annals of Glaciology, Vol. 5, 1984, p. 229.

(2) Ibid.

(3) Micklin (1985), p. 44.

(4) J.P. Bruce and R.L. Pentland, Environment Canada, Water Resources of the 80s, a seminar on the Management of Water Resources, Institute of Public Administration of Canada, presented at Harrison Hot Springs, B.C., 24-26 April 1985, 22 p.

(5) J. Gribbin and M. Kelly, "Climatic Impact of Soviet River Diversions," New Scientist, 6 December 1979, p. 762-765.

POTENTIAL EFFECTS OF CHANGES TO HUDSON BAY

A. Ice Pack and Climate

Although Hudson Bay is governed by somewhat different oceanographic parameters, there are enough similarities to the U.S.S.R. scenarios that the three mechanisms governing local effects on ice pack can be considered to be possible results of diverting the freshwater flow of James Bay south. The present effect of the Hudson and James Bays' ice pack on the weather patterns and flora in Central Canada is witnessed by the southward dipping of the treeline as the bay is approached. Considering the dependence of treeline on the delicate balance of climatic parameters, any modification to ice pack duration could affect the local or regional climate. Predictions of localized climate effects were made for much smaller-scale developments such as the La Grande on James Bay.(1) The large-scale effects of mechanism 4) (i.e., warming trend) seem unlikely for Hudson Bay as there is not a warm subsurface layer to be released to the surface. An effect on the pycnocline and the water column stability of Hudson Bay is, however, quite possible.

A one-dimensional oceanic mixed layer model, simulating the annual surface layer properties of Hudson Bay indicates their sensitivity to runoff modification. The model is simplistic, partly due to the lack of available data and the number of variables examined, but it does simulate some effects of hydroelectric developments. It does not, however, simulate a condition as extreme as withdrawal of all the freshwater contributed by James Bay (only one of many scenarios possible from the so far vaguely described GRAND Canal scheme). Results of the model indicate that the shallow surface pycnocline of Hudson Bay would be formed earlier in the spring, decreasing the surface layer temperature and salinity, and thus stimulating an increase in ice formation. In the summer, the surface layer salinity would be higher and the temperature would be lower, which decreases the water column stability. As a result, the pycnocline would deepen, which would increase the deviations from normal conditions.(1) Although this indicates there is potential for ice pack and climate modifications, a more complex atmospheric model indicates that the sea surface temperature may be buffered against man-made changes. The model indicates that "a one-degree depression of sea surface temperature in the summer is slowly offset by increased heating and no noticeable change in temperature remains at the end of the fall."(2)

---

(1) Environment Canada, James Bay Hydro-electric Project: A Statement of Environmental Concerns and Recommendations for Protection and Enhancement Measures, Lands Directorate (co-ordinator), Ottawa, 24 March 1975, p. 9-11.

It should be noted that, in conjunction with Soviet water diversions, changes in the Arctic ice pack and the total amount of solar radiation absorbed in polar regions could have broad implications for global atmospheric circulation. As well, over the next century, the greenhouse effect could lead to warmer and wetter conditions in the James Bay area, perhaps resulting in a significant increase in runoff. The possibilities are both speculative and complex.

B. Primary Productivity

Based on the model simulating a 25% ice layer reduction, which is equivalent to a 50% reduction of James Bay freshwater flow, a total diversion of James Bay freshwater might result in only a 1‰ increase in salinity in the summer surface layer of Hudson Bay.(3,4) If this is the case, salinity modification of Hudson Bay may have less biological impact than one might imagine. However, further ramifications of the reduced stability and deeper pycnocline could involve a reduction in primary productivity. Offshore phytoplankton are found in a 20 m layer below the pycnocline where their chlorophyll concentration ranges from 1.8 to 63 times surface chlorophyll layers. It is likely that this subsurface layer contributes significantly to the overall primary productivity of Hudson Bay.(1) If phytoplankton are somewhat restricted to this layer because of nutrient limitations above and light limitations below, a deeper pycnocline may result in the entrainment of nutrients below the photic limits of these phytoplankton.

---

(1) S.J. Prinsenberg, "Effects of the Hydroelectric Developments on the Oceanographic Surface Parameters of Hudson Bay," Atmosphere-Ocean, Vol. 21, No. 4, 1983, p. 418-430.

(2) S.J. Prinsenberg and M. Danard, "Variations in Momentum, Mass and Heat Fluxes Due to Changes in the Sea Surface Temperature of Hudson Bay," Atmosphere-Ocean, (in press) 1985.

(3) Prinsenberg (1983), Atmosphere-Ocean, p. 427-428.

(4) S.J. Prinsenberg, personal communication, September 1985.

Additionally, other aspects of circulation may affect production. For example, if the pycnocline were to deepen (recalling that mixing generally occurs above the pycnocline) the large, unoxidated nutrient reserves of the lower levels of the bay, which normally take four to fourteen years to turn over,(2) might be brought to the surface more rapidly and increase the nutrient composition in the photic zone. The mixing, however, would occur in the fall or winter, the time when the pycnocline is deep (see Figure 2). Although some species of epontic algae(3) photosynthesize at low light levels below ice (0.01% of surface irradiance),(4) it is not known whether the phytoplankton species in question have this ability. As well, the timing would not be characteristic of Arctic waters where a single peak of phytoplankton production normally occurs in the spring.(5)

The relative contribution of nutrients from James Bay to Hudson Bay is unknown. Preliminary budget calculations for the whole Hudson and James Bays system indicate that nitrate and total nitrogen contributions from deepwater mixing and land runoff are of the same order of magnitude. Nitrification appears to be a limiting factor in Hudson Bay; however, nitrification does occur in winter in the neritic(1) James Bay environment.(2) Levels of nitrate and nitrite in the surface ice and in the snow cover are generally a factor of two or three greater than those in the water immediately below the ice. It is therefore possible that melting ice and snow may be an important nutrient source during the spring phytoplankton bloom.(3) In view of these processes and the probable large contribution of James Bay to Hudson Bay, withdrawal of the nutrients associated with the James Bay freshwater influx could severely affect the food chain.

---

(1) J.A. Anderson and J.C. Roff, "Subsurface Chlorophyll - a Maximum in Hudson Bay," Le Naturaliste canadien, Vol. 107, No. 4, 1980, p. 207-213.

(2) Pett and Roff (1982), Le Naturaliste canadien, p. 771-775.

(3) Epontic algae are unicellular algae associated with the lower interface of sea ice.

(4) G.F. Cota, "Photoadaptation of High Arctic Ice Algae," Nature, Vol. 315, 16 May 1985, p. 219-221.

(5) Anderson and Roff (1980), Le Naturaliste canadien, p. 211.

Analysis of aperiodic phytoplankton blooms in Manitounuk Sound, a moderately saline (22‰) coastal embayment of southeast Hudson Bay, indicates that destratification mixes high salinity subsurface water to the surface which is not favourable for the phytoplankton species of the area. The destratification appears to result from current (windinduced) and tidal action and, although this upwelling provides required nutrients from below, it is the moderate salinities of the intermittent stable periods which are productive.(4) The construction of a dam across James Bay could affect aperiodic phytoplankton blooms of coastal embayments in several ways. It could potentially increase the moderate salinity of these localized embayments to a level too high to support production of the commonly-associated phytoplankton species. As well, the dampening effect of James Bay on the tidal action of Hudson and James Bays would be removed by the construction of the dam. The result might be an increase in tidal action (and that associated with wind) which might increase the depth and frequency of aperiodic destratification. Waters of higher salinity might be brought to the surface and the intermittent stable periods, required for production, might be reduced.

---

(1) Neritic - defined as a region of shallow water adjoining the seacoast.

(2) Pett and Roff (1982), Le Naturaliste canadien, p. 776-774.

(3) N.G. Freeman et al., "Physical, Chemical and Biological Features of River Plumes Under an Ice Cover in James and Hudson Bays," Le Naturaliste canadien, Vol. 109, 1982, p. 745-764.

(4) L. Legendre et al., "Aperiodic Changes of Water Column Stability and Phytoplankton in an Arctic Coastal Embayment, Manitounuk Sound, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 775-786.

Long-distance and long-term effects are also possible. Th freshwater contribution from James Bay is a significant part of the tota signal from the Hudson/James Bay system which is detected down the Labrado coast.(1,2) The strength of the signal may be affected because of reduced circulation in Hudson Bay, and the salinity of its waters enterin the Labrador current would be increased. The changes would be received a the Grand Banks in the autumn, the Scotian Shelf during the winter, an Georges Bank probably during the spring. All these areas are productiv fishing grounds possibly already suffering in production because of thei reduced freshwater signals.(3)

C. Aquatic Food Chain

1. Plankton and Macrobenthic Fauna

A reduction in the primary productivity of Hudson Bay woul eventually decrease productivity at all levels of the food chain. Resourc inventories are scant and the relationships between components of all level of the food chain in Hudson Bay are poorly understood. For example ciliates are found in high abundance at the Belcher Islands in southeas Hudson Bay. Although their role has not been adequately described in an ocean, it has been suggested that they do play a significant role in th food chain at the Belchers, where they serve as important predators o phytoplankton and as prey for the larger omnivorous zooplankton.(4) O the 235 phytoplankton species found in Hudson Bay, 42 are freshwater species, reflecting the large freshwater runoff into the bay. Thei ecological role and contribution to total productivity has not bee adequately identified although anadromous fish species are known to follo freshwater plumes out to the bay for feeding.

---

(1) Steve Peck, Marine Environmental Data Services, Fisheries and Oceans (personal communication through P.A. Bolduc), 25 July 1985.

(2) Neu (1982), Part I, p. 8-9.

(3) Ibid.

(4) E.H. Grainger, "Factors Affecting Phytoplankton Stocks and Primary Productivity at the Belcher Islands, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 787-791.

The distribution of macrobenthic fauna in river estuaries is linked to salinity and organic matter content in the sediments. Macrobenthic fauna populations will therefore probably change as a result of a reduction of freshwater at river estuaries, particularly in the estuaries of the southeast coast of Hudson Bay where salinity might increase the most. Such change will be a function of the mode of reproduction of the species, their physiological response to physio-chemical variations and the changes that will occur in the sediments. Species with a pelagic mode of reproduction will probably invade new habitats in the more saline waters of estuaries faster than species without such a mode of reproduction.(1)

2. Fish

There are approximately 60 species of fish found at present in the estuarine fish communities of Hudson Bay and James Bay. Latitudinal differences are found in the composition of the communities with fewer species found in the north where arctic and subarctic species are more prominent.(2) The adaptability of fish species to salinity changes will play a predominant role in determining the composition of estuarine fish communities of the Hudson Bay coast after dam construction.(3) Considerable nearshore habitat would also be lost to marine species currently using this environment. There have been no scientific fish surveys of offshore James Bay and only one survey of offshore Hudson Bay, conducted in 1931. It is generally thought that the potential for a commercial fishery in either bay is low, although there has been some suggestion of potentially exploitable stocks of Greenland cod and capelin.(4)

---

(1) J.F. Grenon, "The Macrobenthic Fauna of the Eastmain Estuary (James Bay, Quebec) Before the Diversion," Le Naturaliste canadien, Vol. 109, 1982, p. 793-802.

(2) R. Morin et al., "Estuarine Fish Communities of the Eastern James-Hudson Bay Coast," Environmental Biology of Fishes, Vol. 5, No. 2, 1980, p. 135-141.

(3) S. Ochman and J. Dodson, "Composition and Structure of the Larval and Juvenile Fish Community of the Eastmain River and Estuary, James Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 803-813.

(4) J.G. Hunter, "Fishes and Fisheries," in C.S. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968, p. 372.

A survey of fisheries potential for supplying feed for 5,000 foxes at a fu farm in operation on the East James Bay coast is in preparation. Because o lack of support, the survey will be localized in the near-offshore of on village. Although fisheries potential in James and Hudson Bay has not bee studied, it is anticipated that it would be negatively affected by th proposed scheme for the reasons outlined above, and as a result of th anticipated reduction in primary production.

Impounding James Bay would have similar implications fo ecological productivity in the newly-formed lake. Virtually all marin organisms would be destroyed. Freshwater fish species presently dominant i Rupert's Bay(1) are the most likely to dominate in the impoundment.(2) However, additional problems might be anticipated as experienc has shown that newly-created northern reservoirs are generally unproductiv and fail to support viable commercial fisheries. In some small Arcti lakes, a salt layer is found at depths resulting in a gradient so stron that the lower layer never mixes with the surface, loses its oxygen content and becomes unproductive. In addition, northern impoundments have bee shown to release contaminants which may accumulate in fish tissues, rendering them unfit for human consumption.

The transfer scheme would also provide the opportunity for inter-basin transfer of exotic species north to south and vice versa. These could include plankton, bacteria, viruses, fish species and their associated parasites (e.g., lamprey) into the James Bay impoundment.

3. Mammals

Little information is available on marine mammals of Hudson Bay or James Bay. Ringed seals and bearded seals are the predominant seal species and it is likely that they, as well as other marine mammals, would be negatively affected by a reduction in productivity at various levels of the food chain. Ringed seals require fast-ice for breeding whereas bearded seals are usually associated with moving pack ice and shallow banks that are free of land-fast ice in the winter.(1) Changes in ice pack regimes may affect either or both species. Ringed seals are found on all coasts of both Hudson Bay and James Bay, where their populations have respectively been estimated at 455,000 and 61,000.(2) The only population estimate for bearded seals is a 1958 figure of 84,000 in Hudson Bay.(3) Smaller populations of harbour seals, which require ice-free conditions in the winter, occur sparingly at isolated localities along all coasts, while small numbers of harp seals are found as far south as the Belcher Islands in the summer. Again, changes in the ice pack, notably a reduction of open water, could result in a reduction of their population. Walrus population estimates in the eastern Canadian Arctic are incomplete. In Hudson Bay, the main concentration is at northeastern Coats Island and southeastern Southampton Island where they are found during all seasons, with an estimated summer population of 2,000. In the 1950s and 1960s, the walrus population of Foxe Basin and Hudson Bay together was estimated at 8,500. They were found on both coasts of Hudson Bay and as far south as the Belcher Islands.(4)

---

(1) Morin et al. (1980), p. 135-141.

(2) J. Dodson, Université Laval, personal communication, September 1985.

Polar bears are directly dependent on seals as their main food source and would be affected by any long-term changes in seal populations. The large numbers of polar bears found on the coasts of Hudson Bay and northern James Bay during the summer and fall, and on islands in northern James Bay, could lose important denning areas due to flooding and construction. In particular, areas around Cape Henrietta Maria, which is a likely candidate site for dam construction, support a large population of polar bears.(1)

---

(1) A.W. Mansfield, "Seals and Walruses," in C.S. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968, p. 379-382.

(2) A 1975 estimate in: Department of Fisheries and Oceans Canada, Brief submitted to the Royal Commission on Seals and the Sealing Industry in Canada, Vol. 1, May 1985, p. 95.

(3) Mansfield (1968), p. 382.

(4) R.R. Reeves, "Atlantic Walrus (Odobenus rosmarus rosmarus): A Literature Survey and Status Report," Wildlife Research Report 10, U.S. Department of the Interior, Fish and Wildlife, Washington, D.C., 1978, p. 16.

White whales (also known as belugas) are the main species of whale found in Hudson Bay. The most recent report estimates that a population of 8,000 to 9,000 belugas summer in western Hudson Bay and winter in open areas of Hudson Strait and Ungava Bay.(2) Other evidence suggests a portion of the population uses the polynya of northwest Hudson Bay and James Bay in winter.(3,4) Additionally, a small population of a few hundred, reduced from an estimated historical population of 5,000, spend the summer on the east coast of Hudson Bay.(5)

Estuaries appear important to Belugas, serving as feeding grounds, areas for as yet unexplained social behaviour and as calving grounds. It is hypothesized that the higher water temperatures of estuaries may lessen the shock of birth and reduce heat loss in the first few days after birth until sufficient subcutaneous fat has been acquired.(6) Loss or alteration of estuaries, which appear to be traditionally used, could further affect whale behaviour (i.e., migration pattern), reproductive success or both. At present there is considerable concern for the beluga populations because of continued harvesting by native peoples and because of effects of present hydroelectric developments. As the distribution and movements of belugas are greatly influenced by ice conditions,(1) changes in ice pack regimes may have significant consequences. In conjunction with the possibility of lower water temperatures, a reduction in circulation of Hudson Bay could threaten the existence of polynyas. A reduced circulation could also reduce the upwelling of nutrients that occurs in the northwest of Hudson Bay, an area which appears biologically important for other marine species as well. A closing of open areas would be disastrous for any non-migratory populations of marine mammals.

---

(1) J.P. Prevett, "The Status of Polar Bears in Ontario," Le Naturaliste canadien, Vol. 109, 1982, p. 933-939.

(2) K.J. Finley et al., "The Belugas (Delphinapterus leucas) of Northern Quebec: Distribution, Abundance, Stock Identity, Catch History and Management," Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1123, November 1982, p. 13.

(3) C.J. Jonkel, "White Whales Wintering in James Bay," Journal Fisheries Research Board of Canada, Vol. 26, No. 8, 1969, p. 2205-2207.

(4) D.E. Sergeant, "Biology of White Whales (Delphinapterus leucas) in Western Hudson Bay," Journal Fisheries Research Board of Canada, Vol. 30, No. 8, 1973, p. 1065.

(5) Finley et al. (1982), p. V.

(6) Sergeant (1973), p. 1080.

An endangered population of possibly less than 100 bowhead whales inhabits northern Hudson Bay, most probably on a year-round basis, although once again data are limited. This Hudson Bay/Foxe Basin population is known to summer near Southampton Island in the same northwest area as the beluga whales, although possibly displaced a little north because of competition. It is not known whether the whole summer population winters in Hudson Bay but sightings have been made near Southampton Island, in the Foxe Basin shore leads and polynyas, and in the dense shifting pack ice of northeast Hudson Bay and west Hudson Strait.(2,3)

A strong, circumstantial argument suggests that ice conditions affect the survival of bowhead whales. An increase in ice cover could increase the possibility of entrapment in the ice, as bowheads tend to remain near the edge of ice, and would restrict their movement to preferred feeding grounds.(4) An increase in ice cover and a decrease in productivity in the food chain would not be beneficial to the population's present tenuous existence.

---

(1) Finley et al. (1982), p. 2.

(2) R.R. Reeves et al., "Distribution and Migration of the Bowhead Whale, Balaena mysticetus, in the Eastern North American Arctic," Arctic, Vol. 36, No. 1, March 1983, p. 5-64.

(3) P.L. McLaren and R.A. Davis, Winter Distribution of Arctic Marine Mammals in Ice-Covered Waters of Eastern North America, unpublished OLABS Program Report, 1982, p. 63.

(4) E.D. Mitchell and R.R. Reeves, "Factors Affecting Abundance of Bowhead Whales (Balaena mysticetus) in the Eastern Arctic of North America, 1915-1980," Biological Conservation, Vol. 22, 1982, p. 59-78.

D. Waterfowl, Shorebirds and Seabirds(1)

1. Waterfowl

The Hudson Bay and James Bay coasts are a major migration pathway for many species of geese and ducks en route between breeding and wintering areas. Approximately 2.5 million Lesser Snow Geese and 200,000 Canada Geese use staging areas on the coastal marshes of the Hudson Bay Lowland during spring and fall migration. In an average year, 1.5 million of the Lesser Snow Geese use the James Bay coastal areas.(2) The high fertility and productivity of the coastal zone support a wide range of food species which enable reproduction, growth of juveniles and fattening of all ages prior to the fall migration. In the spring, Lesser Snow Geese and Canada Geese are able to maintain weight for the final migration to their breeding areas by feeding on early exposed new growth and the perennating organs of arrowgrass. A major breeding colony of Lesser Snow Geese is located just west of Cape Henrietta Maria, with smaller breeding areas located on Akimiski Island near Churchill and in the vicinity of Eskimo Pt., N.W.T. (i.e., on Hudson and James Bays). Approximately 75% of the Atlantic Brant goose population is concentrated on the eel grass beds of the Quebec coast and parts of the Ontario coast of James Bay, and almost the whole North American population of Black Scoters may stage in southern James Bay (up to 320,000 in the fall). Additionally, many other species of waterfowl use the inshore intertidal and brackish coastal habitats which are very susceptible to changes in salinity. Major species include Black Duck, Pintail, Mallard, Wigeon, Green-winged Teal and Scaup. Mergansers and loons make extensive use of offshore waters for feeding and significant numbers of Common Eider spend the winter in James Bay. Although spring migrants use the southern James Bay shoreline the most heavily because it is the first section to melt, the coast of Hudson Bay is also used.

---

(1) References for this section are a series of four papers in: Le Naturaliste canadien, Vol. 109, 1982, p. 895-932, in addition to personal communication with the Canadian Wildlife Service, Ottawa, August 1985, unless otherwise cited.

(2) J.P. Prevett et al., "Fall Foods of Lesser Snow Geese in the James Bay Region," Journal of Wildlife Management, Vol. 43, No. 3, 1979, p. 737-742.

2. Shorebirds

Probably the entire Hudson Bay population of Hudsonian Godwits use staging areas on the west coast of both bays to accumulate fat reserves that are essential for their direct flight to South America. They, as does probably the entire North American population of Red Knots use the lower intertidal zone, which would be destroyed in James Bay and possibly severely altered in Hudson Bay by the proposed project. Both are species for which there is a considerable conservation concern at present. Other important species include Dunlin, Black-bellied Plover, Golden Plover, Semi-palmated Plover, Greater and Lesser Yellowlegs, Sanderlings, four species of Sandpiper, Whimbrel and Marbled Godwit. The coasts of both bays are also used by the nearly-extinct Eskimo Curlew. Effects of dam construction would almost certainly be negative, particularly in James Bay (e.g., delayed ice breakup, lower productivity of marshes and invertebrates and alteration of seasonal resources) and could result in the destruction of all or a substantial portion of many North American migratory bird populations.

3. Seabirds

The area of northern Hudson Bay and west Hudson Strait supports the third largest seabird population in the Canadian Arctic, dominated by the Thick-billed Murre. The absence of other common species and the rapidly fluctuating population of the Murres suggest a delicate balance of food supply and population size. A reduction in food supply, one possible effect of terminating the flow of James Bay, might seriously affect the Murre population. Again, further study of oceanographic processes and their effect on food reserves is needed.

ADDITIONAL EFFECTS AND CONCERNS

"James Bay may be interpreted as a sediment sump for the centre of the continent."(1) Rivers are estimated to bring 4.12×10^7

---

(1) K. Kranck and A. Ruffman, "Sedimentation in James Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 353.

tonnes of sediment per year into James Bay.(1) Although this would only form a 0.33 mm layer if distributed evenly over the whole bay, the dam construction could alter the present patterns of sediment deposition, complicating engineering processes of water transfer, and affect water quality and aquatic life within the embayment. With a removal of estuarine circulation it is likely that coarse suspended particles would tend to settle out of the water column sooner, resulting in the formation of river deltas. In contrast, the very fine sediments would tend to stay in suspension longer because a freshwater regime would result in less flocculation and precipitation.(2) Potential effects could be a reduction in primary productivity as less light becomes available and an increased potential for clogging gill and filtering mechanisms of aquatic organisms (e.g., fish gills).

Although engineering plans are still speculative, estimates indicate that over one billion cubic metres of landfill will be required to construct a dam across the opening between James and Hudson Bays.(3) The source of this landfill has not been identified, but the removal of such quantities is certain to have some detrimental impacts.

The transfer scheme itself could have severe implications for fisheries resources by restricting the movement of fish with dams and the possibility of entrainment and death of juvenile fish at pumping facilities, particularly at the James Bay source. Potential flooding along river valley corridors used for the water transfer would be accompanied by direct biological impacts and social disruption.

---

(1) Ibid., p. 353-361.

(2) K. Kranck, Bedford Institute of Oceanography, personal communication, September 1985.

(3) A. Bruneau, The Grand Canal Scheme, notes presented during a meeting at the Bedford Institute of Oceanography, 7 January 1985, p. 2.

DISCUSSION

It is difficult to predict adequately the potential effects of terminating the freshwater flow of James Bay into Hudson Bay, when so little is known. Valiant attempts to model the oceanographic and atmospheric effects of partial diversions have been made in spite of an incomplete and inadequate database. Resource inventories of many biological entities which may be affected are also incomplete, although it is quite clear that a major portion of the North American migratory bird population would be negatively affected. As a consequence, most of the comments throughout the preceding text are speculative and were made on the premise of the construction of a dam across the entrance between Hudson and James Bays which would result in a total withdrawal of the freshwater of James Bay from Hudson Bay. This is only one possible scenario for the proposed "Grand Canal" scheme of which many parameters are still not defined. For example, what flow rate(s) will continue into Hudson Bay during which seasons? In an excessively moist or dry year, will the rates vary?

The examination of analogous situations and the modelling of this and other diversion projects have raised the concerns of possible long-term ecological and climatic effects. Particularly in conjunction with U.S.S.R. water diversions, how might possible major changes in the Arctic ice pack affect atmospheric circulation, temperature and precipitation patterns over the northern hemisphere? What will be the quality and extent of change in the freshwater signal entering the Labrador current, and what will be its effects? Downstream effects, which receiving areas of the diversions may encounter, have not been addressed but also warrant attention. These complex questions and countless others must be addressed before such a large-scale diversion is contemplated.

SELECTED REFERENCES

(1) Anderson, J.A., and J.C. Roff, "Subsurface Chlorophyll - a Maximum in Hudson Bay," Le Naturaliste canadien, Vol. 107, No. 4, 1980.

(2) Bourassa, Robert, Power from the North, Prentice Hall, New Jersey, 1985.

(3) Bruce, J.P., and R.J. Pentland, Environment Canada, Water Resources of the 80s, a seminar on the Management of Water Resources, Institute of Public Administration of Canada, presented at Harrison Hot Springs, B.C., 24-26 April 1985, 22 p.

(4) Bruneau, A., The Grand Canal Scheme, notes presented during a meeting at the Bedford Institute of Technology, 7 January 1985.

(5) Cota, G.F., "Photoadaptation of High Arctic Ice Algae," Nature, Vol. 315, 16 May 1985.

(6) Department of Fisheries and Oceans, Canada, Brief submitted to the Royal Commission on Seals and the Sealing Industry in Canada, Vol. 1, May 1985.

(7) Dunbar, M.J., "Oceanographic Research in Hudson and James Bays, "Le Naturaliste canadien, Vol. 109, 1982.

(8) Energy, Mines and Resources Canada, The National Atlas of Canada, Macmillan Company of Canada Ltd., Ottawa, 1974.

(9) Environment Canada, James Bay Hydro-electric Project: A Statement of Environmental Concerns and Recommendations for Protection and Enhancement Measures, Lands Directorate (Co-ordinator), Ottawa, 24 March 1975.

(10) Finley, K.J., et al., "The Belugas (Delphinapterus Leucas) of Northern Quebec: Distribution, Abundance, Stock Identity, Catch History and Management, "Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1123.

(11) Freeman, N.G., et al., "Physical, Chemical and Biological Features of River Plumes under an Ice Cover in James and Hudson Bays," Le Naturaliste canadien, Vol. 109, 1982.

(12) Grainger, E.H., "Factors Affecting Phytoplankton Stocks and Primary Productivity at the Belcher Islands, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982.

(13) Grenon, J.F., "The Macrobenthic Fauna of the Eastmain Estuary (James Bay, Quebec) Before the Diversion," Le Naturaliste canadien, Vol. 109, 1982.

(14) Gribbin, J., and M. Kelly, "Climatic Impact of Soviet River Diversions," New Scientist, 6 December 1979.

(15) Holt, T., et al,. "Cryospheric Impacts of Soviet River Diversion Schemes," Annals of Glaciology", Vol. 5, 1984.

(16) Hunter, J.G., "Fishes and Fisheries," in CS. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968.

(17) Jonkel, C.J., "White Whales Wintering in James Bay," Journal Fisheries Research Board of Canada, Vol. 26, No. 8, 1969.

(18) Krank, K., and A. Ruffman, "Sedimentation in James Bay," Le Naturaliste canadien, Vol. 109, 1982.

(19) Legendre, L., et. al., "Aperiodic Changes of Water Column Stability and Phytoplankton in an Arctic Coastal Embayment, Manitounuk Sound, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982.

(20) McLaren, P.L., and R.A. Davis, Winter Distribution of Arctic Marine Mammals in Ice-Covered Waters of Eastern North American Arctic, unpublished OLABS Program Report, 1982.

(21) Mansfield, A.W., "Seals and Walruses," in C.S. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968.

(22) Micklin, P.P., "The Vast Diversion of Soviet Rivers," Environment, Vol. 27, No. 2, March 1985.

(23) Mitchell, E.D., and R.R. Reeves, "Factors Affecting Abundance of Bowhead Whales (Balaena mysticetus) in the Eastern Arctic of North America, 1915-1980," Biological Conservation, Vol. 22, 1982.

(24) Morin, R., et al., "Estuarine Fish Communities of the Eastern James-Hudson Bay coast," Environmental Biology of Fishes, Vol. 5, No. 2, 1980.

(25) Le Naturaliste canadien, Four papers, Vol. 109, 1982.

(26) Neu, H.J.A., "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part I," Marine Pollution Bulletin, Vol. 13, No. 1, January 1982.

(27) Neu, H.J.A., "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part II," Marine Pollution Bulletin, Vol. 13, No. 2, February 1982.

(28) Neu, H.J.A., "Runoff Regulation for Hydropower and its Effects on the Ocean Environment," Canadian Journal of Civil Engineering, Vol. 2, No. 4, 1975.

(29) Neu, H.J.A., "Runoff Regulation for Hydro-Power and Its Effect on the Ocean Environment," Hydrological Sciences Bulletin, Vol. 21, No. 3, September 1976.

(30) Ochman, S., and J. Dodson, "Composition and Structure of the Larval and Juvenile Fish Community of the Eastmain River and Estuary, James Bay," Le Naturaliste canadien, Vol. 109, 1982.

(31) Pett, R.J., and J.C. Roff, "Some Observations and Deductions Concerning the Deep Waters of Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982.

(32) Prevett, J.P., et al., "Fall Foods of Lesser Snow Geese in the James Bay Region," Journal of Wildlife Management, Vol. 43, No. 3, 1979.

(33) Prevett, J.P., "The Status of Polar Bears in Ontario," Le Naturaliste canadien, Vol. 109, 1982.

(34) Prinsenberg, S.J., "Circulation Pattern and Current Structure of Hudson Bay," Canadian Inland Seas, Elsevier Oceanographic Series (in press), 1985.

(35) Prinsenberg, S.J., "Effects of the Hydroelectric Developments on the Oceanographic Surface Parameters of Hudson Bay," Atmosphere - Ocean, Vol. 21, No. 4, 1983.

(36) Prinsenberg, S.J., "Freshwater Contents and Heat Budgets of James Bay and Hudson Bay," Continental Shelf Research, Vol. 3, No. 2, 1984.

(37) Prinsenberg, S.J., "Man-Made Changes in the Freshwater Input Rates of Hudson and James Bays," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 37, 1980.

(38) Prinsenberg, S.J., "Salinity and Temperature Distributions of Hudson Bay and James Bay," Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

(39) Prinsenberg, S.J., "Time Variability of Physical Oceanographic Parameters in Hudson Bay,", Le naturaliste canadien, Vol. 109, 1982.

(40) Prinsenberg, S.J., and M. Danard, "Variations in Momentum, Mass and Heat Fluxes Due to changes in the Sea Surface Temperature of Hudson Bay," Atmosphere - Ocean (in press), 1985.

(41) Reeves, R.R. "Atlantic Walrus (Odobenus rosmarus rosmarus): A Literature Survey and Status Report," Wildlife Research Report 10, U.S. Department of the Interior, Fish and Wildlife, Washington, D.C., 1978.

(42) Reeves, R.R., "Distribution and Migration of the Bowhead Whale, Balaena mysticetus, in the Eastern North American Arctic," Arctic, Vol. 36, No. 1, March 1983.

(43) Semtner, A.J., "The Climate Response of the Arctic Ocean to Soviet River Diversions," Annals of Glaciology, Vol. 5, 1984.

(44) Sergeant, D.E., "Biology of White Whales (Delphinapterus Leucas) in Western Hudson Bay," Journal Fisheries Research Board of Canada, Vol. 30, No. 8, 1973.

99999 Pam:627.8:(*623)
MIL

MILKO, Robert J.
Potential environmental effects of the proposed James Bay Diversion

Borrower's Name | Date Due

RETUR

99999 Pam:627.8:(*623)
MIL

MILKO, Robert J.
Potential environmental effects of the proposed James Bay Diversion

Boreal Institute for Northern Studies Library
CW 401 Bio Sci Bldg
The University of Alberta
Edmonton, AB Canada T6G 2E9

University of Alberta Library
0 1620 0335 9906